Renewable and Sustainable Energy Reviews 16 (2012) 6333–6339

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Comparative studies on Performance evaluation of a two stroke copper coated spark ignition engine with alcohols with catalytic converter

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ARTICLE INFO

Article history:
Received 3 February 2012
Received in revised form
1 July 2012
Accepted 15 July 2012
Available online 31 August 2012

Keywords:
S.I. engine
CE
CCE
Fuel performance
Exhaust emissions
Catalytic converter
Combustion characteristics

ABSTRACT

Aim: Investigations were carried out to evaluate the performance of a two-stroke, single cylinder, spark ignition (SI) engine, with alcohol blended gasoline (80% gasoline, 20% methanol by vol; 80% gasoline and 20% ethanol by volume) having copper coated engine [CCE, copper-(thickness, 300 μm) coated on piston crown, inner side of cylinder head] provided with catalytic converter with sponge iron as catalyst and compared with conventional SI engine (CE) with pure gasoline operation.
Study design: Performance parameters of brake thermal efficiency, exhaust gas temperature and volumetric efficiency were determined at various values of brake mean effective pressure (BMEP).
Methodology: A microprocessor-based analyzer was used for the measurement of carbon monoxide (CO) and un-burnt hydro carbons (UBHC) in the exhaust of the engine at various values of BMEP. Aldehydes were measured by dinitrophenyl hydrazine (DNPH) method at peak load operation of the engine.
Brief results: CCE with alcohol blended gasoline considerably reduced pollutants in comparison with CE with pure gasoline operation. Catalytic converter with air injection significantly reduced pollutants with test fuels on both configurations of the engine. Gasohol improved the performance of the both versions of the engine in comparison with methanol blended gasoline. On the other hand, methanol blended gasoline effectively reduced the emissions when compared with gasohol in both versions of the engine.

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1. Introduction

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by the public of the country. The tremendous rate at which population explosion is taking place imposes expansion of the cities to larger areas and common man is forced, these days to travel long distances even for their routine works. This in turn is causing an increase in vehicle population at an alarming rate thus bringing in pressure in Government to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles. The large amount of pollutants emitting out from the exhaust of the automotive vehicles run on fossil fuels is also increasing as this is proportional to number of vehicles. Hence the search for alternate fuels has become pertinent apart from effective fuel utilization which

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http://dx.doi.org/10.1016/j.rser.2012.07.008

has been the concern of the engine manufacturers, users and researchers involved in combustion and alternate fuel research. Alcohols both ethyl alcohol and methyl alcohol are promising substitutes as alternate fuels for gasoline as their properties are compatible and particularly their octane numbers are more than 100. Hence engine modification is not necessary if they are blended with gasoline in small quantities. Investigations were carried out [1–8] on CE with alcohols and was reported that performance improved and exhaust emissions reduced with alcohol operation. Carbon monoxide (CO) and un-burnt hydrocarbons (UBHC), major exhaust emissions formed due to incomplete combustion of fuel, cause many human health disorders [9,10] and inhaling of these pollutants cause severe headache, vomiting sensation, respiratory problems, reduction of hemoglobin in the blood etc. Such pollutants also cause detrimental effects [11] on animal and plant life, besides environmental disorders. Hence control of these pollutants is necessary and urgent. Age and maintenance of the vehicle were some of the reasons [11–13] for the formation of pollutants. Aldehydes [14–16], which are intermediate compounds formed in combustion, are carcinogenic in nature and cause detrimental effects on human health and hence control of these pollutants is an immediate task. Engine modification [17–22] with copper coating on piston crown and inner side of cylinder head improved engine performance as copper is a good conductor of heat and combustion improved with copper coating. Catalytic converter is effective [23–28] in reduction of pollutants in SI engine. The present paper reported the performance, emissions characteristics and combustion characteristics of a two-stroke SI engine with alcohol blended gasoline in different configurations of the engine with catalytic converter with sponge iron as catalyst and compared with gasoline operation on CE.

2. Methodology

The experimental setup used for the investigations on CCE with alcohols is shown in Fig. 1. A two- stroke, single-cylinder, air-cooled, SI engine (brake power 2.2 kW at the speed of 3000 rpm) was coupled to a rope brake dynamometer for measuring its brake power. The bore and stroke of engine cylinder was 57 mm each. Compression ratio of engine was 7.5:1. Exhaust gas temperature, speed, torque, fuel consumption and air flow rate of the engine were measured with electronic sensors. In catalytic coated engine, piston crown and inner surface of cylinder head were coated with copper by flame spray gun. The surface of the components to be coated were cleaned and subjected to sand blasting.

A bond coating of nickel–cobalt–chromium of thickness 100 μm was sprayed over which copper (89.5%), aluminum (9.5%) and iron (1%) alloy of thickness 300 μm was coated with METCO (Trade name of the company) flame spray gun.

The coating has very high bond strength and does not wear off even after 50 h of operation [17]. CO and UBHC emissions in engine exhaust were measured with Netel Chromatograph analyzer. The accuracy of CO/UBHC analyzer is 0.1%. A catalytic converter [23] (Fig. 2) was fitted to the exhaust pipe of the engine.

The provision was also made to inject a definite quantity of air into the catalytic converter. Air quantity drawn from compressor and injected into converter was kept constant so that back-pressure does not increase. Experiments were carried out on CE and CCE with different test fuels (pure gasoline and alcohol blended gasoline (20% by vol)) under different operating conditions of catalytic converter like set-A, without catalytic converter and without air injection; set-B, with catalytic converter and without air injection; and set-C, with catalytic converter and with air injection. For measuring aldehydes in the exhaust of the engine, a wet chemical method [14] was employed. The exhaust of the engine was bubbled through 2,4-dinitrophenyl hydrazine (DNPH) in hydrochloric acid solution and the hydrazones formed from aldehydes were extracted into chloroform and were analyzed by high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine. The Piezo electric transducer, fitted on the cylinder head to measure pressure in the combustion chamber was connected to a console, which in turn was connected to Pentium personal computer. TDC encoder provided at the extended shaft of the dynamometer was connected to the console to measure the crank angle of the engine. Pressure–crank angle diagram was obtained on the screen of the personal computer. A special P-θ software package evaluated the combustion characteristics such as peak pressure (PP),

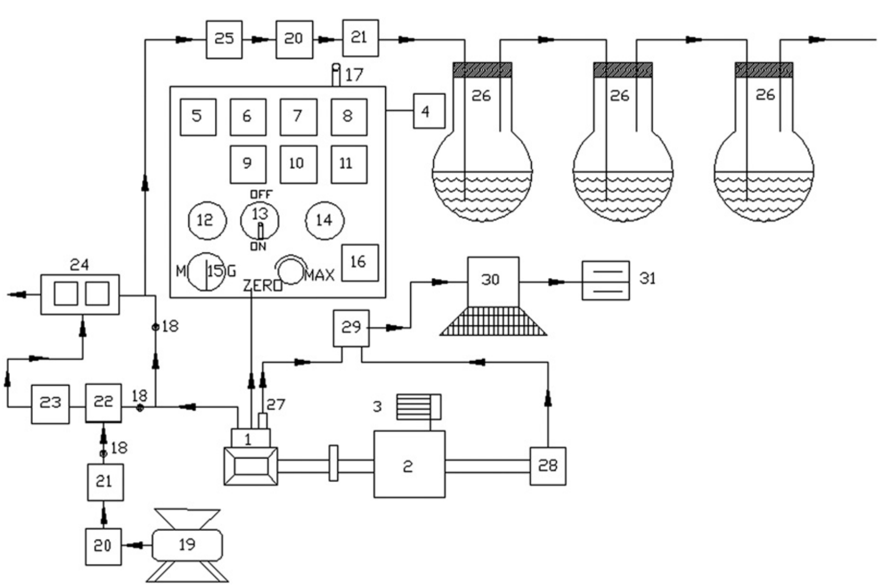


Fig. 1. Experimental setup. 1: engine; 2: electrical swinging field dynamometer; 3: loading arrangement; 4: fuel tank; 5: torque indicator/controller sensor; 6: fuel rate indicator sensor; 7: hot wire gas flow indicator; 8: multi channel temperature indicator; 9: speed indicator; 10: air flow indicator; 11: exhaust gas temperature indicator; 12: mains ON; 13: engine ON/OFF switch; 14: mains OFF; 15: motor/generator option switch; 16: heater controller; 17: speed indicator; 18: directional valve, 19: air compressor; 20: rotometer; 21: heater; 22: air chamber; 23: catalytic chamber; 24: CO/HC analyzer; 25: filter; 26: round bottom flasks containing DNPH solution; 27: piezoelectric transducer; 28: TDC encoder; 29: consol; 30: pentium personal computer; and 31: printer.

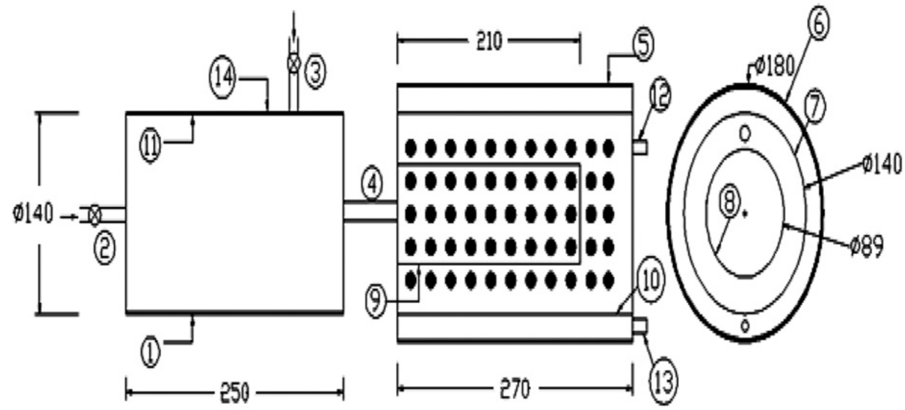


Fig. 2. Details of catalytic converter. 1: air chamber; 2: inlet for air chamber from the engine; 3: inlet for air chamber from the compressor; 4: outlet for air chamber; 5: catalytic chamber; 6: outer cylinder; 7: intermediate-cylinder; 8: inner-cylinder; 9: inner sheet; 10: intermediate sheet; 11: outer sheet; 12: outlet for exhaust gases; 13: provision to deposit the catalyst; and 14: insulation. *Note*: All dimensions are in mm.

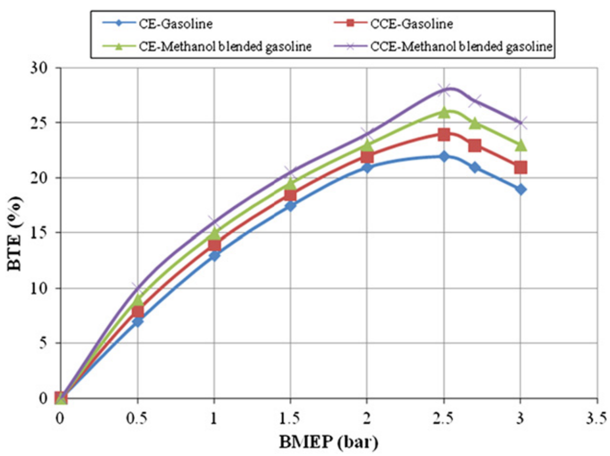


Fig. 3. Variation of brake thermal efficiency (BTE) with BMEP in different versions of the engine with pure gasoline and methanol blended gasoline at a compression ratio of 7.5:1 and at a speed of 3000 rpm.

time of occurrence of peak pressure (TOPP), maximum rate of pressure rise (MRPR) and time of occurrence of maximum rate of pressure rise (TOMRPR) and heat release from the signals of pressure and crank angle. Combustion characteristics were evaluated at the peak load operation of the engine.

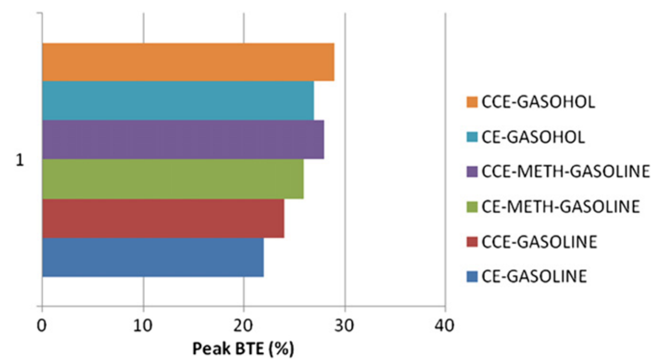


Fig. 4. Bar charts showing the variation of peak BTE in both versions of the engine with test fuels.

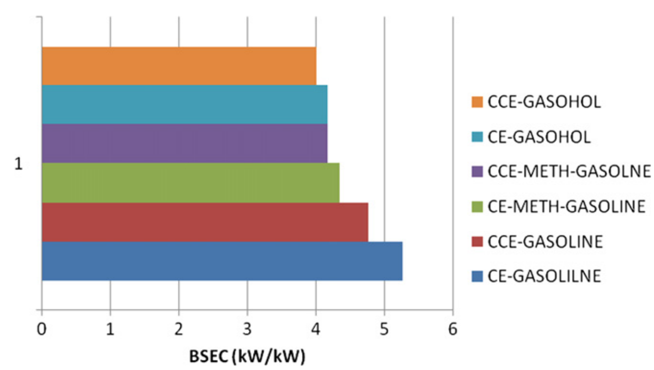


Fig. 5. Bar charts showing the variation of BSEC at peak load operation in both versions of the engine with test fuels.

3. Results and discussions

3.1. Performance Parameters

The curves from Fig. 3 indicate that brake thermal efficiency (BTE) increased up to 80% of full load and beyond that load, it decreased with increase of BMEP for both versions of the engine with test fuels.

This was due to increase of fuel conversion efficiency up to 80% of full load and beyond that load, with increase of friction power, performance deteriorated. Higher BTE was observed with methanol blended gasoline over pure gasoline at all loads due to lower stoichiometric air requirement of methanol blended gasoline over pure gasoline operation. CCE showed higher thermal efficiency when compared to CE with both test fuels at loads, particularly at near full load operation, due to efficient combustion with catalytic activity, which was more pronounced at peak load, as catalytic activity increased with prevailing high temperatures at peak load.

It is observed from Fig. 4, gasohol (gasoline 80% and ethanol 20% by volume) showed higher peak BTE when compared with other test fuels in both versions of the engine as its calorific value is higher when compared with methanol blended gasoline.

Brake specific energy consumption (BSEC), defined as energy consumed by the engine in producing 1 kW brake power was lower for ethanol operation at peak load operation when compared with methanol operation as indicated in Fig. 5. This was due to higher calorific value of ethanol in comparison with methanol, which showed higher energy substitution of ethanol, as energy substitution was the product of mass of fuel consumed and calorific value of the fuel. The catalytic activity was highly pronounced in gasohol operation rather than methanol operation, as it depended on temperature. Since methanol has higher latent

heat of evaporation, it absorbs temperature from surroundings leading to decrease the temperature. Hence CCE with gasohol operation at peak load operation showed improved performance in comparison with methanol operation.

From Fig. 6, it is noticed that exhaust gas temperature (EGT) increased with BEMP at all loads for both versions of the engine with test fuels.

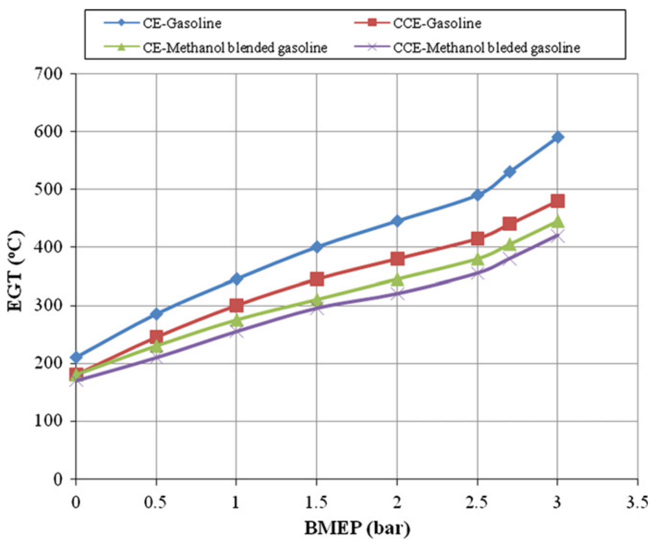


Fig. 6. Variation of EGT with BMEP with pure gasoline and methanol blended gasoline in both configurations of the engine.

EGT was lower with methanol blended gasoline when compared to pure gasoline at all loads in CE and CCE because with methanol blended gasoline, work transfer from piston to gases in cylinder at the end of compression stroke was too large leading to reduction in the magnitude of EGT. This was also due to high latent heat of evaporation of methanol. CCE registered lower EGT when compared to CE for both test fuels, which confirmed efficient combustion with the CCE than CE

From Fig. 7, it is evident that methanol blended gasoline showed lower EGT when compared with other test fuels in both versions of the engine. This was due to higher value of latent heat of evaporation.

Curves from Fig. 8 indicate that volumetric efficiency (VE) decreased with increase of BMEP. CCE showed higher VE at all loads in comparison with CE with different test fuels due to reduction of residual charge and deposits in the combustion chamber of CCE when compared to CE, which shows the same trend as reported earlier [13]. Methanol blended gasoline showed higher VE than pure gasoline operation in both versions of the engine at all loads, due to increase of mass and density of air with reduction of temperature of air due to high latent heat of evaporation of methanol.

From Fig. 9, it is noticed that VE was observed to be higher with methanol blended gasoline in comparison with other test fuels. This was due to higher latent heat of evaporation.

3.2. Exhaust Emissions

From Table 1, it is observed that CO emissions decreased with alcohols when compared with gasoline operation on both

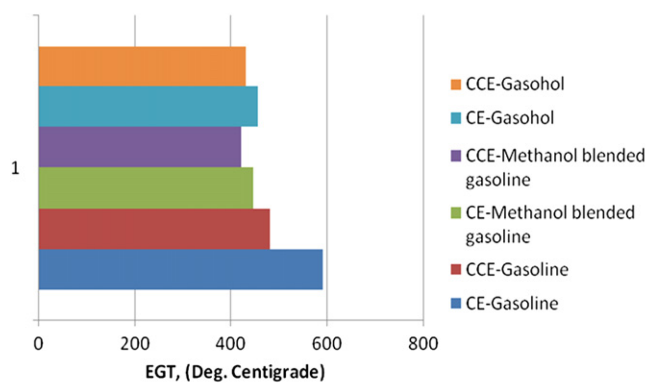


Fig. 7. Bar charts showing the variation of EGT at peak load operation in both versions of the engine with test fuels.

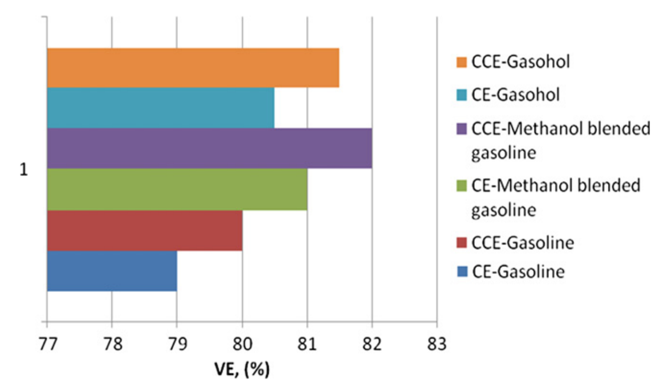


Fig. 9. Bar charts showing the variation of VE at peak load operation in both versions of the engine with test fuels.

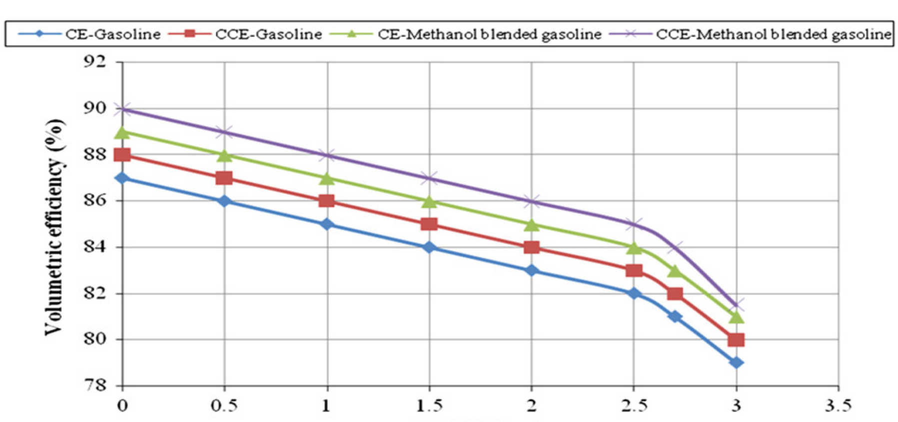


Fig. 8. Variation of volumetric efficiency (VE) with BMEP with pure gasoline and methanol blended gasoline with different configurations of the engine.

Table 1
Data of 'CO' emissions (%) at peak load operation.

Set	Conventional engine (CE)			Copper coated engine (CCE)		
	Pure gasoline	Methanol blended gasoline	Gasohol	Pure gasoline	Methanol blended gasoline	Gasohol
Set-A	5.0	3.0	3.5	4.0	2.4	2.9
Set-B	3.0	1.8	2.3	2.4	1.44	1.9
Set-C	2.0	1.2	1.5	1.6	0.96	1.26

versions of the engine. The combustion of methanol produces more water vapor than free carbon atoms as methanol has lower C/H ratio of 0.25 against 0.50 of gasoline. Methanol has oxygen in its structure and hence its blends have lower stoichiometric air requirements compared to gasoline. Therefore more oxygen that is available for combustion with the blends of methanol and gasoline, leads to reduction of CO emissions. Methanol dissociates in the combustion chamber of the engine forming hydrogen, which helps the fuel–air mixture to burn quickly and thus increases combustion velocity, which brings about complete combustion of carbon present in the fuel to CO_2 and also CO to CO_2 thus making leaner mixture more combustible, causing reduction of CO emissions. CCE reduces CO emissions in comparison with CE. Copper or its alloys acts as catalyst in combustion chamber, whereby facilitates effective combustion of fuel leading to formation of CO_2 instead of CO. Similar trends were observed with Ref. [17] with pure gasoline operation on CCE. From the table, it could be observed that CO emissions decreases considerably with catalytic operation in set-B with methanol blended gasoline and further decrease in CO was pronounced with air injection with the same fuel. The effective combustion of the methanol blended gasoline itself decreased CO emissions in both configurations of the engine. CO emissions were observed to be more with gasohol operation in comparison with methanol blended gasoline in both versions of the engine at different operating conditions of the catalytic converter. This was due to the reason that C/H ratio of gasohol is higher (0.33) in comparison with methanol blended gasoline (0.25).

From Table 2, it is evident that UBHC emissions were similar to those of CO emissions in both versions of the engine with both test fuels. Methanol blended operation decreased UBHC emissions marginally in comparison with gasohol operation in both versions of the engine.

From Table 3, it is observed that formaldehyde emissions in the exhaust decreased considerably with the use of catalytic converter, which is more pronounced with an air injection into the converter. Methanol blend increased formaldehyde emissions considerably due to partial oxidation compared to pure gasoline. The low combustion temperature lead to produce partially oxidized carbonyl (aldehyde) compounds with gasohol. CCE decreases formaldehyde emissions when compared to CE. The trend exhibited by acetaldehyde emissions was same as that of formaldehyde emissions.

However, acetaldehyde emission was observed to be more with ethanol blend compared to methanol blend of gasoline in both versions of the engine (Table 4). The partial oxidation of ethanol during combustion predominantly leads to formation of acetaldehyde. Copper (catalyst) coated engine decreased aldehydes emissions considerably by effective oxidation when compared to CE. Catalytic converter with air injection drastically decreased aldehyde emissions

3.3. Combustion characteristics

From Fig. 10, it is observed that PP increased with gasohol operation in comparison with methanol blended gasoline operation.

Table 2
Data of 'UBHC' emissions (ppm) at peak load operation.

Set	Conventional engine (CE)			Copper coated engine (CCE)		
	Pure gasoline	Methanol blended gasoline	Gasohol	Pure gasoline	Methanol blended gasoline	Gasohol
Set-A	750	525	562	600	420	450
Set-B	450	315	340	360	252	270
Set-C	300	210	225	240	168	180

Table 3
Data of formaldehyde emissions (% concentration) at peak load operation.

Set	Conventional engine (CE)			Copper coated engine (CCE)		
	Pure gasoline	Methanol blended gasoline	Gasohol	Pure gasoline	Methanol blended gasoline	Gasohol
Set-A	9.1	23.6	14.6	6.8	13.6	9.31
Set-B	6.3	10.8	7.0	4.1	10.2	5.0
Set-C	3.5	8.0	5.9	3.2	3.5	3.93

Table 4
Data of acetaldehyde emissions (% concentration) at peak load operation.

Set	Conventional engine (CE)			Copper coated engine (CCE)		
	Pure gasoline	Methanol blended gasoline	Gasohol	Pure gasoline	Methanol blended gasoline	Gasohol
Set-A	7.7	12.3	16.8	4.9	9.3	12.6
Set-B	4.9	6.5	8.4	3.5	7.7	7.5
Set-C	2.1	3.8	7.0	1.4	3.9	5.2

The ratios of moles of products to the reactants for gasoline and alcohols are as follows:

$$1.0588C_8H_{18}+12.5O_2+47N_2 \rightarrow 8CO_2+9H_2O+47N_2$$
(60.5 mol) (64.0 mol)

$$1.065C_2H_5OH+3O_2+11.3N_2 \rightarrow 2CO_2+3H_2O+11.3N_2$$
(15.3 mol) (16.3 mol)

$$1.061CH_3OH+1.5O_2+5.65N_2 \rightarrow CO_2+2H_2O+5.65N_2$$
(8.15 mol) (8.65 mol)

Assuming all the fuel enter the engine completely evaporated, the fuel giving largest number of moles of product per mole of reactant should produce the greatest pressure in the cylinder after the combustion, all other factors being equal (which incidentally are not) The greater pressure taken alone would result in an increase in engine power. But an engine may not ingest its mixture with the fuel already evaporated. Under such conditions the number of moles of products should be examined on the basis of number of moles of air inducted since fuel occupies very little volume. Consider the fuel to enter the cylinder in liquid state points to a somewhat enhanced power output from ethanol on this rather simple basis (Table 5).

From Fig. 11, it is noticed that TOPP decreased with alcohol operation in comparison with pure gasoline operation on both versions of the engine.

TOPP was found to be lower (nearer to TDC) with CCE with methanol blended gasoline compared with CE with pure gasoline,

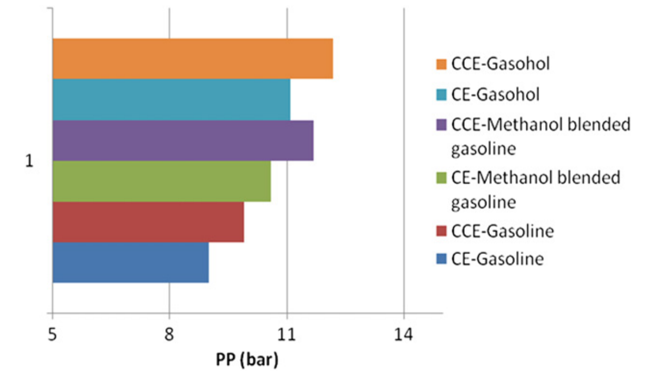


Fig. 10. Bar charts showing the variation of PP at peak load operation in both versions of the engine with test fuels.

Table 5
Comparative moles of products per moles of air at chemically correct mixture ratio neglecting dissociation.

Fuel	Dry basis		Wet basis	
	Ratio	Compared to gasoline	Ratio	Coppmared to gasoline
Gasoline	1.058	1.000	1.075	1.000
Ethanol	1.065	1.008	1.140	1.061
Methanol	1.061	1.004	1.210	1.126

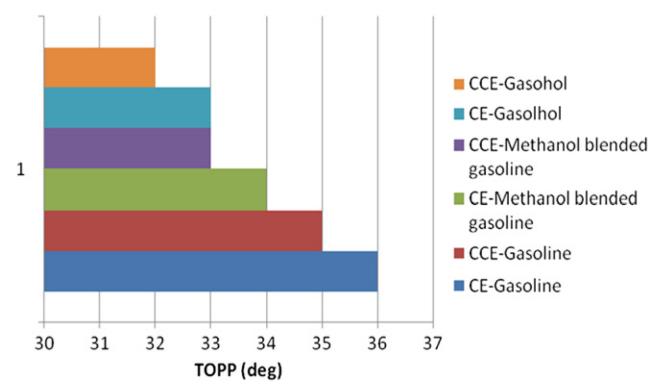


Fig. 11. Bar charts showing the variation of TOPP at peak load operation in both versions of the engine with test fuels.

which confirmed that performane improved with efficient combustion with CCE. This was because CE exhibited higher temperatures of combustion chamber walls leading to continuation of combustion, giving peak pressures away from TDC. However, this phenomenon was nullified with CCE with methanol blended gasoline because of reduced temperature of combustion chamber walls thus bringing the peak pressures closure to TDC. CE with gasoline operation exhibited pressure on the piston by the time the piston already started executing downward motion from TDC to BDC leading to decrease PP and increase TOPP. CCE with gasoline operation improved combustion due to catalytic activity, PP was oberved to be higher than CE with same test fuel. Higher PP and lower TOPP confirmed that performance of the CCE with methanol blended gasoline was improved causing efficient energy utilizaion on the piston. Methanol addition improved the combustion process, reduced the crevices flow energy, reduced the cylinder temperature, reduced the ignition delay, speeded up the flame front propagation, and reduced the duration of combustion. TOPP was lower with ethanol operation when compared with methanol operation on both versions of the engine, which confirmed that performance improved with ethanol operation.

From Fig. 12, it is observed that the trends of MRPR was similar to those of PP.

The increase in maximum heat release (calculated from heat release diagram obtained from software package; Fig. 13) indicated that the combustion in the CCE with methanol blended gasoline has improved when compared with CE with gasoline due to the combustion of the relatively lean air–fuel mixtures, which showed that combustion was efficient with CCE with methanol blended gasoline It was found that heat release for gasohol was more when compared with methanol blended gasoline in both versions of the engine. This was due to high calorific value of ethanol in comparison with methanol, so as to give more energy supplied to the engine as energy supplied to the engine was the product of rate of mass of fuel burnt and calorific value of the fuel.

4. Conclusions

Peak BTE increased by 18% with gasohol operation on CCE in comparison with pure gasoline operation on CE. Peak BTE increased by 4% with gasohol operation on CCE when compared with methanol blended gasoline operation on same configuration of the engine. EGT decreased, while VE increased marginally with alcohol operation in comparison with pure gasoline operation on CE. Exhaust emissions of CO and UBHC decreased by 20% with CCE when compared with CE with both test fuels. Set-B operation decreased CO and UBHC emissions by 40%, while Set-C operation decreased these emissions by 60% with test fuels when compared

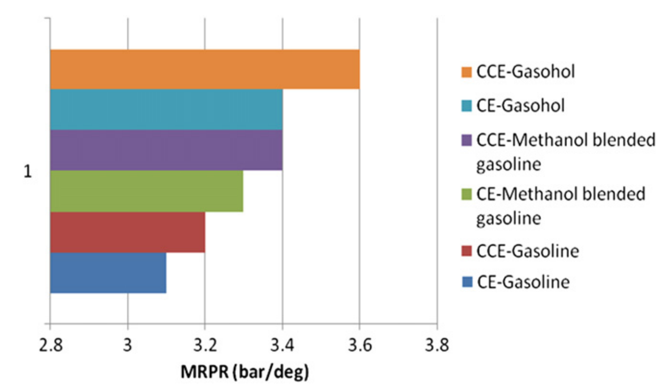


Fig. 12. Bar charts showing the variation of MRPR at peak load operation in both versions of the engine with test fuels.

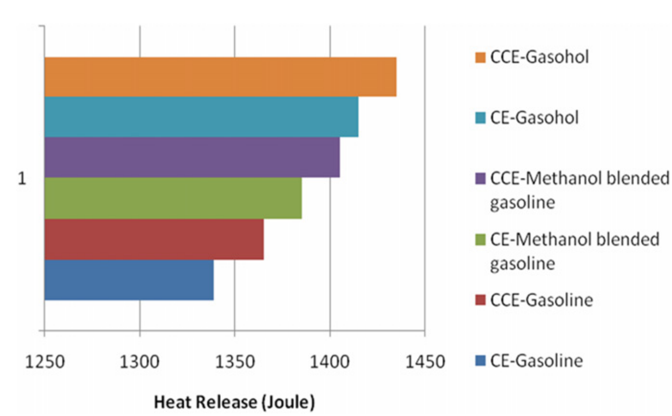


Fig. 13. Bar charts showing the variation of Heat Release at peak load operation in both versions of the engine with test fuels.

to Set-A operation. CCE decreased aldehyde emissions in comparison with CE with alcohol operation. Methanol blended gasoline reduced exhaust emissions effectively in comparison with gasohol operation in both versions of the engine.

Acknowledgements

Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for the facilities provided. Financial assistance from the Andhra Pradesh Council of Science and Technology (APCOST), Hyderabad is greatly acknowledged.

References

[1] Al-Farayedhi AA, Al-Dawood AM, Gandhidasan P. Experimental investigation of spark ignition engine performance using oxygenated fuel. ASME—Journal of Engineering for Gas Turbines and Power, 0022-0825 2004;126:178–91.
[2] Abu Zaid, Badran O, Yamin J. Effect of methanol addition on the performance of spark ignition engines. Energy and Fuels, 0887-0624 2004;18:312–5.
[3] Ceviz MA, Yuksel F. Effects of ethanol-unleaded gasoline blends on cyclic variability and emissions in a spark ignition engine. Applied Thermal Engineering, 01369-4311 2005;25:917–25.
[4] Nakata K. The effect of ethanol fuel on a spark ignition engine. SAE Paper no. 2006-01-3380; 2006.
[5] Pearson RJ. Alcohol based fuels in high performance engines. SAE Paper no. 2007-01-0056; 2007.
[6] Bahattin Celik M. Experimental determination of suitable ethanol–gasoline blend rate at high compression ratio for gasoline engine. Applied Thermal Engineering, 01369-4311 2008;28:396–404.
[7] Al-Baghdadi MARS. Measurement and prediction study of the effect of ethanol blending on the performance and pollutants emission of a four-stroke spark ignition engine. Proceedings of the Institution of Mechanical Engineers 2008;222(5):859–73.
[8] Rodrigo CCosta, José RSodré. Hydrous ethanol vs. gasoline–ethanol blend: engine performance and emissions. Fuel, 0016-2361 2010:287–93.
[9] Fulekar MH. Chemical pollution—a threat to human life. Indian Journal of Environmental Protection, 0253-7141 1999;1:353–9.
[10] Sharma BK, editor. Engineering Chemistry. Meerut: Pragathi Prakashan (P) Ltd.; 2004.
[11] Khopkar SM, editor. Environmental Pollution Analysis. New Delhi: New Age International (P) Ltd, Publishers; 2005.
[12] Usha Madhuri T, Srinivas T, Ramakrishna KA. Study on automobile exhaust pollution with regard to carbon monoxide emissions. Nature, Environment and Pollution Technology, 0971-4871 2003;2:473–4.
[13] Ghose MK, Paul R, Benerjee SK. Assessment of the impact of vehicle pollution on urban air quality. Journal of Environmental Science and Engineering, 0367-827X 2004;46:33–40.
[14] Murthy PVK, Narasimha Kumar S, Murali Krishna MVS, Seshagiri Rao VVR, Reddy DN. Aldehyde emissions from two-stroke and four-stroke spark ignition engines with methanol blended gasoline with catalytic converter. International Journal of Engineering Research and Technology, 0974-3154 2010;3(3):793–802.
[15] Murali Krishna MVS, Narasimha Kumar S, Krishna Murthy PV. Control of aldehyde emissions from copper coated spark ignition engine fueled with alcohol blended gasoline. International Journal of Engineering Research and Applications (IJERA), 2248-9622 2011;1(2):337–40.
[16] Murthy PVK, Narasimha Kumar S, Kishor K, Murali Krishna MVS. Aldehyde emissions from two-stroke and four-stroke spark ignition engines with catalytic converter running on gasohol. SAE International Journal of Fuels and Lubricants, 0350-350X 2011;50(2):137–56.
[17] Nedunchezhian N, Dhandapani S. Experimental investigation of cyclic variation of combustion parameters in a catalytically activated two-stroke SI engine combustion chamber. Engineering Today, 0974-8377 2000;2:11–8.
[18] Murali Krishna MVS, Kishor K. Control of pollutants from copper coated spark ignition engine with methanol blended gasoline. Indian Journal of Environmental Protection, 0972-6101 2005;25(8):732–8.
[19] Murali Krishna MVS, Kishor K. Investigations on catalytic coated spark ignition engine with methanol blended gasoline with catalytic converter. Indian Journal (CSIR) of Scientific and Industrial Research, 0022-4456 2008;67:543–8.
[20] Murali Krishna MVS, Kishor K, Murthy PVK, Gupta AVSSKS, Narasimha Kumar S. Performance evaluation of copper coated four stroke spark ignition engine with gasohol with catalytic converter. International Journal of Engineering Studies, 0975-6469 2010;2(4):465–73.
[21] Narasimha Kumar S, Murali Krishna MVS, Murthy PVK, Seshagiri Rao VVR, Reddy DN. Performance of copper coated two stroke spark ignition engine with gasohol with catalytic converter. International Journal of Innovations in Mechanical and Automobile Engineering, 0974-231X 2011;12(1):36–43.
[22] Murali Krishna MVS, Kishor K, Gupta AVSSKS, Murthy PVK, Narasimha Kumar S. Performance of copper coated two stroke spark ignition engine with methanol blended gasoline with catalytic converter. International Journal of Sustainable and Renewable Energy (American Institute of Physics), 1941-7012 2012;4(1):013102.1–9.
[23] Murali Krishna MVS, Prasad PRK, Ajay Kumar M, Narayana MV, Balu B. Parametric studies of catalytic converter on reduction of carbon monoxide in spark ignition engine with gasohol. Engineering Today, 0974-8377 2005;7(6):3–7.
[24] Murali Krishna MVS, Kishor K, Prasad PRK, Swathy GVV. Parametric studies of pollutants from copper coated spark ignition engine with catalytic converter with gasoline blended methanol. Journal of Current Sciences, 0972-6101 2006;9(2):529–34.
[25] Murali Krishna MVS, Kishor K, Ramana Reddy ChV. Control of carbon monoxide emission in spark ignition engine with methanol blended gasoline and sponge iron catalyst. Ecology, Environment and Conservation, 0971-765X 2008;13(4):13–7.
[26] Ronald MHeck, Robert JFarauto, editors. Catalyltic Air Pollution Control. John Wiley & sons; 2009.
[27] Kishor K, Murali Krishna MVS, Gupta AVSSKS, Narasimha Kumar S, Reddy DN. Emissions from copper coated spark ignition engine with methanol blended gasoline with catalytic converter. Indian Journal of Environmental Protection, 0972-6101 2010;30(3):177–83.
[28] Murali Krishna MVS, Kishor K, Murthy PVK, Gupta, AVSSKS. Parametric studies on catalytic converter on reduction of pollutants in copper coated two stroke spark ignition engine with methanol blended gasoline. In: Proceedings of the 22nd national conference on IC engines and combustion. Calicut: National Institute of Technology; 2011. p. 329–33.